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DESCRIPTION

REDUCTION GEAR FOR WALKING ASSISTANCE SYSTEM

FIELD OF THE INVENTION

The present invention relates to a walking assistance system that assists elderly people with weakened muscle strength or injured people to walk, climb up and down stairs, stand up from a seated posture, sit down from a standing posture, etc. so as to facilitate movement, thus suppressing degradation in muscle strength and correcting the gait mode, and, in particular, it relates to a reduction gear for the walking assistance system.

BACKGROUND ART

Such a walking assistance system has already been proposed in Japanese Patent Application No. 2001-109046 related to an application of the present applicant. This walking assistance system includes an electric actuator fitted to user's leg joints (i.e., a hip joint and a knee joint), and the actuator is operated by supplying electric power from a power source within a backpack carried by the user on the back so as to generate a joint torque for extending/bending each joint, thus assisting the user in carrying out a movement such as walking.

Furthermore, a reduction gear in which a plurality of planetary gear mechanisms are axially stacked in multiple stages so as to achieve a large reduction ratio with a small size is known from Japanese Patent Application Laid-open No. 8-247225 and Japanese Patent Application Laid-open No. 11-37226.

The above-mentioned conventional walking assistance system includes an actuator integrated with a motor and a reduction gear, and since the

reduction gear is required to have a large reduction ratio, there is the problem that the overall dimensions of the actuator increase. As a result, it becomes difficult to fit the actuator under a user's clothing, and since the actuator is exposed outside the clothing, the appearance is poor.

Although the above-mentioned conventional reduction gear, in which the plurality of planetary gear mechanisms are axially stacked in multiple stages, is excellent in having a large reduction ratio, since the axial dimensions are large, it is not suitable for use in an actuator of a walking assistance system.

DISCLOSURE OF INVENTION

The present invention has been accomplished under the above-mentioned circumstances, and it is an object thereof to achieve a thin reduction gear for a walking assistance system while ensuring that the reduction gear has a sufficient reduction ratio.

In order to attain this object, in accordance with a first aspect of the present invention, there is proposed a reduction gear for a walking assistance system that, in order to assist walking movement by extending/bending a user's leg joint, reduces the speed of rotation of an input shaft driven by a motor and transmits the rotation to an output shaft connected to the leg joint, the reduction gear including the input shaft, the output shaft, a first planetary gear mechanism, and a second planetary gear mechanism disposed coaxially on an axis, the second planetary gear mechanism being disposed so as to substantially overlap the radially outer side of the first planetary gear mechanism, the rotation of the input shaft being reduced in speed by the first planetary gear mechanism and the second planetary gear mechanism and transmitted to the output shaft, the first planetary gear mechanism including a first sun gear provided on the input shaft, a first ring gear rotatably disposed so

as to surround the outer periphery of the first sun gear, a plurality of first planetary gears meshing simultaneously with the first sun gear and the first ring gear, and a first carrier rotatably supporting the first planetary gears, and the second planetary gear mechanism including a second sun gear provided on the outer periphery of the first ring gear, a second ring gear disposed so as to surround the outer periphery of the second sun gear, a plurality of second planetary gears meshing simultaneously with the second sun gear and the second ring gear, and a second carrier rotatably supporting the second planetary gears.

In accordance with this arrangement, since the input shaft, the output shaft, the first planetary gear mechanism, and the second planetary gear mechanism are disposed coaxially on the axis of the reduction gear for the walking assistance system, and the second planetary gear mechanism is disposed so as to substantially overlap the radially outer side of the first planetary gear mechanism, it is possible, while reducing in speed the rotation of the input shaft in two stages by the first and second planetary gear mechanisms and transmitting it to the output shaft, to reduce the axial thickness of the reduction gear compared with a case in which the first and second planetary gear mechanisms are disposed so as to be stacked in the axial direction, thereby improving the appearance when a user is equipped with the walking assistance system.

Furthermore, in accordance with a second aspect of the present invention, in addition to the first aspect, there is proposed the reduction gear for the walking assistance system wherein the first carrier of the first planetary gear mechanism is fixed to a casing, the second ring gear of the second planetary gear mechanism is fixed to the casing, and the second carrier of the second planetary gear mechanism is connected to the output shaft.

In accordance with this arrangement, fixing the first carrier of the first planetary gear mechanism to the casing enables the rotation input from the first sun gear to be output from the first ring gear, and fixing the second ring gear to the casing enables the rotation input into the second sun gear, which is integral with the first ring gear, to be output from the second carrier, thereby enabling the rotation of the input shaft to be reduced in speed in two stages by the first and second planetary gear mechanisms and transmitted to the output shaft.

Moreover, in accordance with a third aspect of the present invention, in addition to the second aspect, there is proposed the reduction gear for the walking assistance system wherein a third planetary gear mechanism is disposed so as to be coaxial with and axially be stacked on the first planetary gear mechanism and the second planetary gear mechanism, the third planetary gear mechanism including a third sun gear provided on the outer periphery of a central part of the second carrier of the second planetary gear mechanism, a third ring gear fixed to the casing and disposed so as to surround the outer periphery of the third sun gear, a plurality of third planetary gears meshing simultaneously with the third sun gear and the third ring gear, and a third carrier rotatably supporting the third planetary gears and connected to the output shaft.

In accordance with this arrangement, fixing to the casing the third ring gear of the third planetary gear mechanism, which is disposed so as to be coaxial with and axially be stacked on the first and second planetary gear mechanisms, enables the rotation input into the third sun gear, which is integral with the second carrier, to be output to the third carrier, thereby enabling the rotation of the input shaft to be reduced in speed in three stages

by the first to the third planetary gear mechanisms and transmitted to the output shaft.

Furthermore, in accordance with a fourth aspect of the present invention, there is proposed a reduction gear for a walking assistance system that, in order to assist walking movement by extending/bending a user's leg joint, reduces the speed of rotation of an input shaft driven by a motor and transmits the rotation to an output shaft connected to the leg joint, the reduction gear including the input shaft, the output shaft, a first planetary gear mechanism, a second planetary gear mechanism, and a third planetary gear mechanism disposed coaxially on an axis, the second planetary gear mechanism being disposed so as to substantially overlap the radially outer side of the first planetary gear mechanism, the third planetary gear mechanism being disposed so as to substantially overlap the radially outer side of the second planetary gear mechanism, the rotation of the input shaft being reduced in speed by the first planetary gear mechanism, the second planetary gear mechanism, and the third planetary gear mechanism and transmitted to the output shaft, the first planetary gear mechanism including a first sun gear provided on the input shaft, a first ring gear formed on the inner periphery of an inside ring member rotatably disposed so as to surround the first sun gear, a plurality of first planetary gears meshing simultaneously with the first sun gear and the first ring gear, and a first carrier fixed to a casing and rotatably supporting the first planetary gears, the second planetary gear mechanism including a second sun gear formed on the outer periphery of the inside ring member, a second ring gear formed on the inner periphery of an outside ring member disposed so as to surround the outer periphery of the second sun gear, a plurality of second planetary gears meshing simultaneously with the second sun gear and the second ring gear, and a second carrier fixed to the

casing and rotatably supporting the second planetary gears, and the third planetary gear mechanism including a third sun gear formed on the outer periphery of the outside ring member, a third ring gear fixed to the casing so as to surround the outer periphery of the third sun gear, a plurality of third planetary gears meshing simultaneously with the third sun gear and the third ring gear, and a third carrier rotatably supporting the third planetary gears and connected to the output shaft.

In accordance with this arrangement, while the input shaft, the output shaft, the first planetary gear mechanism, the second planetary gear mechanism, and the third planetary gear mechanism are disposed coaxially on the axis of the reduction gear for the walking assistance system, fixing the first carrier of the first planetary gear mechanism to the casing enables the rotation input from the input shaft into the first sun gear to be output from the first ring gear; fixing the second carrier to the casing enables the rotation input into the second sun gear, which is integral with the first ring gear, to be output from the second ring gear; and fixing the third ring gear to the casing enables the rotation input into the third sun gear, which is integral with the second ring gear, to be output from the third carrier, thereby enabling the rotation of the input shaft to be reduced in speed in three stages by the first to the third planetary gear mechanisms and transmitted to the output shaft. Furthermore, since the second planetary gear mechanism is disposed so as to substantially overlap the radially outer side of the first planetary gear mechanism, and the third planetary gear mechanism is disposed so as to substantially overlap the radially outer side of the second planetary gear mechanism, it is possible, while reducing in speed the rotation of the input shaft in three stages by the first to the third planetary gear mechanisms and transmitting it to the output shaft, to reduce the axial thickness of the reduction gear compared with a case

in which the first to the third planetary gear mechanisms are all disposed so as to be stacked in the axial direction, thereby improving the appearance when the user is equipped with the walking assistance system.

Moreover, in accordance with a fifth aspect of the present invention, there is proposed a reduction gear for a walking assistance system that, in order to assist walking movement by extending/bending a user's leg joint, reduces the speed of rotation of an input shaft driven by a motor and transmits the rotation to an output shaft connected to the leg joint, the reduction gear including the input shaft, the output shaft, a first planetary gear mechanism, a second planetary gear mechanism, and a third planetary gear mechanism disposed coaxially on an axis, the second planetary gear mechanism being disposed so as to substantially overlap the radially outer side of the first planetary gear mechanism, the third planetary gear mechanism being disposed so as to substantially overlap the radially outer side of the second planetary gear mechanism, the rotation of the input shaft being reduced in speed by the first planetary gear mechanism, the second planetary gear mechanism, and the third planetary gear mechanism and transmitted to the output shaft, the first planetary gear mechanism including a first sun gear provided on the input shaft, a first ring gear fixed to a casing so as to surround the first sun gear, a plurality of first planetary gears meshing simultaneously with the first sun gear and the first ring gear, and a first carrier rotatably supporting the first planetary gears, the second planetary gear mechanism including a second sun gear formed on the outer periphery of the first carrier, a second ring gear fixed to the casing so as to surround the outer periphery of the second sun gear, a plurality of second planetary gears meshing simultaneously with the second sun gear and the second ring gear, and a second carrier rotatably supporting the second planetary gears, and the third

planetary gear mechanism including a third sun gear formed on the outer periphery of the second carrier, a third ring gear fixed to the casing so as to surround the outer periphery of the third sun gear, a plurality of third planetary gears meshing simultaneously with the third sun gear and the third ring gear, and a third carrier rotatably supporting the third planetary gears and connected to the output shaft.

In accordance with this arrangement, while the input shaft, the output shaft, the first planetary gear mechanism, the second planetary gear mechanism, and the third planetary gear mechanism are disposed coaxially on the axis of the reduction gear for the walking assistance system, fixing the first ring gear of the first planetary gear mechanism to the casing enables the rotation input from the first sun gear to be output from the first carrier; fixing the second ring gear to the casing enables the rotation input into the second sun gear, which is integral with the first carrier, to be output from the second carrier; and fixing the third ring gear to the casing enables the rotation input to the third sun gear, which is integral with the second carrier, to be output from the third carrier, thereby enabling the rotation of the input shaft to be reduced in speed in three stages by the first to the third planetary gear mechanisms and transmitted to the output shaft. Furthermore, since the second planetary gear mechanism is disposed so as to substantially overlap the radially outer side of the first planetary gear mechanism, and the third planetary gear mechanism is disposed so as to substantially overlap the radially outer side of the second planetary gear mechanism, it is possible, while reducing in speed the rotation of the input shaft in three stages by the first to the third planetary gear mechanisms and transmitting it to the output shaft, to reduce the axial thickness of the reduction gear compared with a case in which the first to the third planetary gear mechanisms are all disposed so as to be stacked in the

axial direction, thereby improving the appearance when the user is equipped with the walking assistance system.

Moreover, in accordance with a sixth aspect of the present invention, there is proposed a reduction gear for a walking assistance system that, in order to assist walking movement by extending/bending a user's leg joint, reduces the speed of rotation of an input shaft driven by a motor and transmits the rotation to an output shaft connected to the leg joint, the reduction gear including the input shaft, the output shaft, a first planetary gear mechanism, a second planetary gear mechanism, and a third planetary gear mechanism disposed coaxially on an axis, the second planetary gear mechanism being disposed so as to substantially overlap the radially outer side of the first planetary gear mechanism, the third planetary gear mechanism being disposed so as to be stacked on the first planetary gear mechanism and the second planetary gear mechanism in the axial direction, the rotation of the input shaft being reduced in speed by the first planetary gear mechanism, the second planetary gear mechanism, and the third planetary gear mechanism and transmitted to the output shaft, the first planetary gear mechanism including a first sun gear provided on the input shaft, a first ring gear fixed to a casing so as to surround the outer periphery of the first sun gear, a plurality of first planetary gears meshing simultaneously with the first sun gear and the first ring gear, and a first carrier rotatably supporting the first planetary gears, the second planetary gear mechanism including a second sun gear provided on the outer periphery of the first carrier, a second ring gear fixed to the casing so as to surround the outer periphery of the second sun gear, a plurality of second planetary gears meshing simultaneously with the second sun gear and the second ring gear, and a second carrier rotatably supporting the second planetary gears, and the third planetary gear mechanism including a third sun

gear provided on the outer periphery of a central part of the second carrier, a third ring gear fixed to the casing so as to surround the outer periphery of the third sun gear, a plurality of third planetary gears meshing simultaneously with the third sun gear and the third ring gear, and a third carrier rotatably supporting the third planetary gears and connected to the output shaft.

In accordance with this arrangement, while the input shaft, the output shaft, the first planetary gear mechanism, the second planetary gear mechanism, and the third planetary gear mechanism are disposed coaxially on the axis of the reduction gear for the walking assistance system, fixing the first ring gear of the first planetary gear mechanism to the casing enables the rotation input from the input shaft into the first sun gear to be output from the first carrier; fixing the second ring gear to the casing enables the rotation input into the second sun gear, which is integral with the first carrier, to be output from the second carrier; and fixing the third ring gear to the casing enables the rotation input into the third sun gear, which is integral with the second carrier, to be output from the third carrier, thereby enabling the rotation of the input shaft to be reduced in speed in three stages by the first to the third planetary gear mechanisms and transmitted to the output shaft. Furthermore, since the second planetary gear mechanism is disposed so as to substantially overlap the radially outer side of the first planetary gear mechanism, and the third planetary gear mechanism is disposed so as to be stacked on the first planetary gear mechanism and the second planetary gear mechanism in the axial direction, it is possible, while reducing in speed the rotation of the input shaft in three stages by the first to the third planetary gear mechanisms and transmitting it to the output shaft, to reduce the axial thickness of the reduction gear compared with a case in which the first to the third planetary gear mechanisms are all disposed so as to be stacked in the axial direction, thereby

improving the appearance when the user is equipped with the walking assistance system.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 to FIG. 7 show a first embodiment of the present invention; FIG. 1 is a diagram showing a walking assistance system in use, FIG. 2 is a first part view of an exploded perspective view of the walking assistance system, FIG. 3 is a second part view of the exploded perspective view of the walking assistance system, FIG. 4 is a vertical sectional view of an electric actuator of the walking assistance system, FIG. 5 is a sectional view along line 5-5 in FIG. 4, FIG. 6 is a sectional view along line 6-6 in FIG. 4, and FIG. 7 is a skeleton diagram of the electric actuator of the walking assistance system.

FIG. 8 to FIG. 10 show a second embodiment of the present invention; FIG. 8 is a vertical sectional view of an electric actuator of a walking assistance system, FIG. 9 is a sectional view along line 9-9 in FIG. 8, and FIG. 10 is a skeleton diagram of the electric actuator of the walking assistance system.

FIG. 11 to FIG. 13 show a third embodiment of the present invention; FIG. 11 is a vertical sectional view of an electric actuator of a walking assistance system, FIG. 12 is a sectional view along line 12-12 in FIG. 11, and FIG. 13 is a skeleton diagram of the electric actuator of the walking assistance system.

FIG. 14 to FIG. 17 show a fourth embodiment of the present invention; FIG. 14 is a vertical sectional view of an electric actuator of a walking assistance system, FIG. 15 is a sectional view along line 15-15 in FIG. 14, FIG. 16 is a sectional view along line 16-16 in FIG. 14, and FIG. 17 is a skeleton diagram of the electric actuator of the walking assistance system.

BEST MODE FOR CARRYING OUT THE INVENTION

A first embodiment of the present invention is explained below with reference to FIG. 1 to FIG. 7.

As shown in FIG. 1 to FIG. 3, a walking assistance system of the present invention includes a backpack 11 carried by a user on the back, a pair of left and right first electric actuators 12 applying a torque to left and right hip joints, a pair of left and right second electric actuators 13 applying a torque to left and right knee joints, an abdominal belt 14 made of a flexible resin and detachably fitted around the user's abdomen, upper leg supports 15f and 15r made of a flexible resin, split into front and rear portions, and detachably fitted around the user's left and right thighs, lower leg supports 16f and 16r made of a flexible resin, split into front and rear portions, and detachably fitted around the user's left and right lower legs, and two suspenders 17 extending from a front part of the abdominal belt 14 and connected to a rear part of the abdominal belt 14 via the user's shoulders. FIG. 3 shows the upper leg supports 15f and 15r and the lower leg supports 16f and 16r for a left leg, and those for a right leg, which are not illustrated, are laterally symmetrical and have the same structure.

A first link 18 and a reinforcing member 19 are secured by bolts so as to hold an outer face and an inner face of each of left and right sides of the abdominal belt 14 therebetween. A second link 20 bendably connected to the lower end of the first link 18 via the first electric actuator 12 is secured by bolts to the outside of the rear upper leg support 15r. In this arrangement, a pivoting support for the first link 18 and the second link 20, that is, the first electric actuator 12, is positioned outside the user's hip joint.

An outside third link 21 and an inside third link 22 are secured by bolts to the outside and the inside respectively of the rear upper leg support 15r,

and an outside fourth link 23 and an inside fourth link 24 are secured by bolts to the outside and the inside respectively of the rear lower leg support 16r. The lower end of the outside third link 21 and the upper end of the outside fourth link 23 are bendably connected to each other via the second electric actuator 13, and the lower end of the inside third link 22 and the upper end of the inside fourth link 24 are bendably connected to each other via a hinge 25. In this arrangement, pivoting supports of the two third links 21 and 22 and the two fourth links 23 and 24, that is, the second electric actuator 13 and the hinge 25, are positioned on the outside and the inside of the user's knee joint.

Housed within the backpack 11, which is detachably fitted to the suspenders 17, are an electronic control unit 26 for controlling the operation of the first electric actuators 12 and the second electric actuators 13, an indicator 27 for indicating the state of torque generated by each of the actuators 12 and 13, a motor driver 28 for driving a motor of each of the actuators 12 and 13, and a power source 29 (e.g., an Ni-Zn battery) for supplying electric power to the motors and the electronic control unit 26.

The first electric actuators 12 and the second electric actuators 13 have a common structure, and are formed from a DC motor and a reduction gear, a casing thereof is secured by bolts to the lower end of the first link 18, and an output shaft thereof is joined by a bolt 30 to the upper end of the second link 20. Driving the first electric actuator 12 therefore generates a torque for rotating the second link 20 relative to the first link 18, thus enabling the user's hip joint to be extended/bent. Furthermore, the second electric actuator 13 has a casing thereof secured by bolts to the lower end of the outside third link 21 and an output shaft thereof joined to the upper end of the outside fourth link 23 by a bolt 30. Driving the second electric actuator 13 therefore generates a

torque for rotating the outside fourth link 23 relative to the outside third link 21, thus enabling the user's knee joint to be extended/bent.

The structure of the first electric actuator 12 is now explained with reference to FIG. 4 to FIG. 7. The structure of the second electric actuator 13 is the same as that of the first electric actuator 12.

A casing 41 of the first electric actuator 12 is formed in a bottomed cylindrical shape having an axis L as the center. The casing 41 is formed by layering a first support ring 42, a second support ring 43, a support plate 44, a motor housing 45, and a motor cover 46 and integrally securing them with a plurality of bolts 47. A motor 48 is housed within the motor housing 45 and the motor cover 46, and a reduction gear 49 is housed within the first support ring 42 and the second support ring 43. An input shaft Si of the reduction gear 49 is supported on the support plate 44 and the motor housing 45 via ball bearings 50 and 51, a rotor 52 of the motor 48 is fixed to the input shaft Si, and a stator 53 surrounding the outer periphery of the rotor 52 is fixed to the motor housing 45. A permanent magnet 52a and a coil 53a are provided on the rotor 52 and the stator 53 respectively, and when the coil 53a is energized, the input shaft Si rotates together with the rotor 52.

The reduction gear 49 includes a first planetary gear mechanism P_1 and a second planetary gear mechanism P_2 housed inside the second support ring 43, and a third planetary gear mechanism P_3 housed inside the first support ring 42. The first planetary gear mechanism P_1 is disposed radially inside the second planetary gear mechanism P_2, and the third planetary gear mechanism P_3 is disposed outside, in the axis L direction, the first and second planetary gear mechanisms P_1 and P_2.

The first planetary gear mechanism P_1 includes a first sun gear ZS_1, a first ring gear ZR_1, a plurality of first planetary gears ZP_1, and a first carrier C_1.

The first sun gear ZS_1 is connected to a shaft end of the input shaft Si via an electromagnetic clutch 54. The first ring gear ZR_1 is formed integrally with the inner periphery of a ring member 55 disposed rotatably around the axis L. The first carrier C_1, which rotatably supports the first planetary gears ZP_1 meshing simultaneously with the first sun gear ZS_1 and the first ring gear ZR_1, is formed as part of the support plate 44. The first planetary gear mechanism P_1 is therefore of a star type in which the first carrier C_1 is fixed and the first ring gear ZR_1 is rotatable, and when the first sun gear ZS_1, which is connected to the input shaft Si via the electromagnetic clutch 54, rotates, the rotation is reduced in speed and reversed, and output to the first ring gear ZR_1 (i.e., the ring member 55).

The reduction ratio of the star type first planetary gear mechanism P_1 is defined as nr_1/ns_1, where ns_1 is an input rotational speed of the first sun gear ZS_1 and nr_1 is an output rotational speed of the first ring gear ZR_1. If zs_1, zr_1, and zp_1 denote the number of teeth of the first sun gear ZS_1, the first ring gear ZR_1, and the first planetary gear ZP_1 respectively, the reduction ratio nr_1/ns_1 is given by

$$nr_1/ns_1 = -zs_1/zr_1. \qquad (1)$$

The minus sign of the right-hand side of Equation (1) indicates that the direction of rotation of the first ring gear ZR_1 is opposite to the direction of rotation of the first sun gear ZS_1.

The second planetary gear mechanism P_2 includes a second sun gear ZS_2, a second ring gear ZR_2, a plurality of second planetary gears ZP_2, and a second carrier C_2. The second sun gear ZS_2 is formed on the outer periphery of the ring member 55, on the inner periphery of which is formed the first ring gear ZR_1. The second ring gear ZR_2 is formed integrally with the inner periphery of the second support ring 43, which is fixed to the casing 41. The

second carrier C_2, which rotatably supports the second planetary gears ZP_2 meshing simultaneously with the second sun gear ZS_2 and the second ring gear ZR_2, is rotatably supported on the inner periphery of the second support ring 43 via a ball bearing 56. The second planetary gear mechanism P_2 is therefore of a planetary type in which the second ring gear ZR_2 is fixed and the second carrier C_2 is rotatable, and when the second sun gear ZS_2, which is an input member, rotates, the rotation is reduced in speed and output in the same rotational sense to the second carrier C_2.

The reduction ratio of the planetary type second planetary gear mechanism P_2 is defined as nc_2/ns_2, where ns_2 is an input rotational speed of the second sun gear ZS and nc_2 is an output rotational speed of the second carrier C_2. If zs_2, zr_2, and zp_2 denote the number of teeth of the second sun gear ZS_2, the second ring gear ZR_2, and the second planetary gear ZP_2 respectively, the reduction ratio nc_2/ns_2 is given by

$$nc_2/ns_2 = zs_2/(zs_2 + zr_2). \qquad (2)$$

The third planetary gear mechanism P_3 includes a third sun gear ZS_3, a third ring gear ZR_3, a plurality of third planetary gears ZP_3, and a third carrier C_3. The third sun gear ZS_3 is formed integrally with the outer periphery of a central part of the second carrier C_2 of the second planetary gear mechanism P_2. The third ring gear ZR_3 is formed integrally with the inner periphery of the first support ring 42, which is fixed to the casing 41. The third carrier C_3, which rotatably supports the third planetary gears ZP_3 meshing simultaneously with the third sun gear ZS_3 and the third ring gear ZR_3, is rotatably supported on the inner periphery of the first support ring 42 via a ball bearing 57. The third planetary gear mechanism P_3 is therefore of a planetary type in which the third ring gear ZR_3 is fixed and the third carrier C_3 is rotatable, and when the third sun gear ZS_3, which is an input member, rotates, the rotation is reduced in

speed and output in the same rotational sense to the output shaft So, which is integral with the third carrier C_3.

The reduction ratio of the planetary type third planetary gear mechanism P_3 is defined as nc_3/ns_3, where ns_3 denotes an input rotational speed of the third sun gear ZS_3 and nc_3 denotes an output rotational speed of the third carrier C_3. If zs_3, zr_3, and zp_3 denote the number of teeth of the third sun gear ZS_3, the third ring gear ZR_3, and the third planetary gear ZP_3 respectively, the reduction ratio nc_3/ns_3 is given by

$$nc_3/ns_3 = zs_3/(zs_3 + zr_3). \qquad (3)$$

Since the output rotational speed nr_1 of the first ring gear ZR_1, which is the output member of the first planetary gear mechanism P_1, is equal to the input rotational speed ns_2 of the second sun gear ZS_2, which is the input member of the second planetary gear mechanism P_2, and the output rotational speed nc_2 of the second carrier C_2, which is the output member of the second planetary gear mechanism P_2, is equal to the input rotational speed ns_3 of the third sun gear ZS_3, which is the input member of the third planetary gear mechanism P_3, the product of the reduction ratio nr_1/ns_1 of the first planetary gear mechanism P_1 shown in Equation (1), the reduction ratio nc_2/ns_2 of the second planetary gear mechanism P_2 shown in Equation (2), and the reduction ratio nc_3/ns_3 of the third planetary gear mechanism P_3 shown in Equation (3) is given by the ratio nc_3/ ns_1 of the rotational speed nc_3 of the third carrier C_3 of the third planetary gear mechanism P_3, the third carrier C_3 being the output member of the reduction gear 49, relative to the rotational speed ns_1 of the first sun gear ZS_1 of the first planetary gear mechanism P_1, the first sun gear ZS_1 being the input member of the reduction gear 49.

$$(nr_1/ns_1) \times (nc_2/ns_2) \times (nc_3/ns_3) = nc_3/ns_1 \qquad (4)$$

From Equation (1) to Equation (3), the reduction ratio nc_3/ns_1 of the reduction gear 49 is given by

$$nc_3/ns_1 = (-zs_1/zr_1) \times \{zs_2/(zs_2 + zr_2)\} \times \{zs_3/(zs_3 + zr_3)\} \qquad (5)$$

and in the embodiment, since the number of teeth of each gear is set as follows:

$zs_1 = 18$ $\quad zp_1 = 27$ $\quad zr_1 = 72$

$zs_2 = 96$ $\quad zp_2 = 24$ $\quad zr_2 = 144$

$zs_3 = 36$ $\quad zp_3 = 54$ $\quad zr_3 = 144$,

the reduction ratio nc_3/ns_1 of the reduction gear 49 obtained by substituting these numbers of teeth in Equation (5) is 1/50. That is, when the input shaft Si of the reduction gear 49 rotates 50 times, the output shaft So rotates once in the opposite direction.

As hereinbefore described, since the reduction gear 49 is formed by connecting the first to the third planetary gear mechanisms P_1 to P_3, it is possible to increase the torque of the motor 48 while ensuring that there is a sufficient reduction ratio. Furthermore, since the second planetary gear mechanism P_2 is disposed so as to overlap the radially outer side of the first planetary gear mechanism P_1, it is possible to reduce the thickness in the axis L direction of the reduction gear 49 compared with a case in which the first to the third planetary gear mechanisms P_1 to P_3 are all disposed so as to be stacked in the axis L direction. That is, the first electric actuators 12 and the second electric actuators 13 can be made compact by suppressing the thickness of the reduction gear 49 to a thickness corresponding to two planetary gear mechanisms while ensuring that there is a reduction ratio corresponding to three planetary gear mechanisms, thereby enabling fitting under a user's clothing with a good appearance.

The structure of a first electric actuator 12 related to a second embodiment of the present invention is now explained with reference to FIG. 8 to FIG. 10. The structure of a second electric actuator 13 is the same as that of the first electric actuator 12.

A casing 41 of the first electric actuator 12 is formed in a bottomed cylindrical shape having an axis L as the center. The casing 41 is formed by layering a support ring 42, a support plate 44, a motor housing 45, and a motor cover 46 and integrally securing them with a plurality of bolts 47. A motor 48 is housed within the motor housing 45 and the motor cover 46, and a reduction gear 49 is housed within the support ring 42. An input shaft Si of the reduction gear 49 is supported on the support plate 44 and the motor cover 46 via ball bearings 50 and 51, a rotor 52 of the motor 48 is fixed to the input shaft Si, and a stator 53 surrounding the outer periphery of the rotor 52 is fixed to the motor housing 45. A permanent magnet 52a and a coil 53a are provided on the rotor 52 and the stator 53 respectively, and when the coil 53a is energized, the input shaft Si rotates together with the rotor 52.

The reduction gear 49, which is housed within the support ring 42, includes a first planetary gear mechanism P_1, a second planetary gear mechanism P_2, and a third planetary gear mechanism P_3; the second planetary gear mechanism P_2 is disposed radially outside the first planetary gear mechanism P_1, and the third planetary gear mechanism P_3 is disposed radially outside the second planetary gear mechanism P_2.

The first planetary gear mechanism P_1 includes a first sun gear ZS_1, a first ring gear ZR_1, a plurality of first planetary gears ZP_1, and a first carrier C_1. The first sun gear ZS_1 is connected to a shaft end of the input shaft Si via an electromagnetic clutch 54. The first ring gear ZR_1 is formed integrally with the inner periphery of an inside ring member 55i disposed so as to surround the

axis L. The first carrier C_1, which rotatably supports the first planetary gears ZP_1 meshing simultaneously with the first sun gear ZS_1 and the first ring gear ZR_1, is provided as a portion close to the center of the support plate 44. The first planetary gear mechanism P_1 is therefore of a star type in which the first ring gear ZR_1 is rotatable and the first carrier C_1 is fixed, and when the first sun gear ZS_1, which is connected to the input shaft Si via the electromagnetic clutch 54, rotates, the rotation is reduced in speed and reversed, and output to the first ring gear ZR_1.

The reduction ratio of the star type first planetary gear mechanism P_1 is defined as nr_1/ns_1, where ns_1 is an input rotational speed of the first sun gear ZS_1 and nr_1 is an output rotational speed of the first ring gear ZR_1. If zs_1, zr_1, and zp_1 denote the number of teeth of the first sun gear ZS_1, the first ring gear ZR_1, and the first planetary gear ZP_1 respectively, the reduction ratio nr_1/ns_1 is given by

$$nr_1/ns_1 = -zs_1/zr_1. \qquad (6)$$

The minus sign of the right side of Equation (6) indicates that the direction of rotation of the first ring gear ZR_1 is opposite to the direction of rotation of the first sun gear ZS_1.

The second planetary gear mechanism P_2 includes a second sun gear ZS_2, a second ring gear ZR_2, a plurality of second planetary gears ZP_2, and a second carrier C_2. The second sun gear ZS_2 is formed on the outer periphery of the inside ring member 55i. The second ring gear ZR_2 is formed integrally with the inner periphery of an outside ring member 55o disposed so as to surround the axis L. The second carrier C_2, which rotatably supports the second planetary gears ZP_2 meshing simultaneously with the second sun gear ZS_2 and the second ring gear ZR_2, is provided as a portion close to the outer periphery of the support plate 44. The second planetary gear mechanism P_2 is

therefore of a star type in which the second ring gear ZR_2 is rotatable and the second carrier C_2 is fixed, and when the second sun gear ZS_2, which is integral with the first ring gear ZR_1, rotates, the rotation is reduced in speed and reversed, and output to the second ring gear ZR_2.

The reduction ratio of the star type second planetary gear mechanism P_2 is defined as nr_2/ns_2, where ns_2 is an input rotational speed of the second sun gear ZS_2 and nr_2 is an output rotational speed of the second ring gear ZR_2. If zs_2, zr_2, and zp_2 denote the number of teeth of the second sun gear ZS_2, the second ring gear ZR_2, and the second planetary gear ZP_2, respectively, the reduction ratio nr_2/ns_2 is given by

$$nr_2/ns_2 = -zs_2/zr_2. \qquad (7)$$

The minus sign of the right-hand side of Equation (7) indicates that the direction of rotation of the second ring gear ZR_2 is opposite to the direction of rotation of the second sun gear ZS_2.

The third planetary gear mechanism P_3 includes a third sun gear ZS_3, a third ring gear ZR_3, a plurality of third planetary gears ZP_3, and a third carrier C_3. The third sun gear ZS_3 is formed integrally with the outer periphery of the outside ring member 55o. The third ring gear ZR_3 is formed integrally with the inner periphery of the support ring 42, which is fixed to the casing 41. The third carrier C_3, which rotatably supports the third planetary gears ZP_3 meshing simultaneously with the third sun gear ZS_3 and the third ring gear ZR_3, is rotatably supported on the inner periphery of the support ring 42 via a ball bearing 57. The third planetary gear mechanism P_3 is therefore of a planetary type in which the third ring gear ZR_3 is fixed and the third carrier C_3 is rotatable, and when the third sun gear ZS_3, which is an input member, rotates, the rotation is reduced in speed in the same direction and output to the output shaft So, which is integral with the third carrier C_3.

The reduction ratio of the planetary type third planetary gear mechanism P_3 is defined as nc_3/ns_3, where ns_3 denotes an input rotational speed of the third sun gear ZS_3 and nc_3 denotes an output rotational speed of the third carrier C_3. If zs_3, zr_3, and zp_3 denote the number of teeth of the third sun gear ZS_3, the third ring gear ZR_3, and the third planetary gear ZP_3 respectively, the reduction ratio nc_3/ns_3 is given by

$$nc_3/ns_3 = zs_3/(zs_3 + zr_3). \qquad (8)$$

Since the output rotational speed nr_1 of the first ring gear ZR_1, which is the output member of the first planetary gear mechanism P_1, is equal to the input rotational speed ns_2 of the second sun gear ZS_2, which is the input member of the second planetary gear mechanism P_2, and the output rotational speed nr_2 of the second ring gear ZR_2, which is the output member of the second planetary gear mechanism P_2, is equal to the input rotational speed ns_3 of the third sun gear ZS_3, which is the input member of the third planetary gear mechanism P_3, the product of the reduction ratio nr_1/ns_1 of the first planetary gear mechanism P_1 shown in Equation (6), the reduction ratio nr_2/ns_2 of the second planetary gear mechanism P_2 shown in Equation (7), and the reduction ratio nc_3/ns_3 of the third planetary gear mechanism P_3 shown in Equation (8) is given by the ratio nc_3/ns_1 of the rotational speed nc_3 of the third carrier C_3 of the third planetary gear mechanism P_3, the third carrier C_3 being the output member of the reduction gear 49, relative to the rotational speed ns_1 of the first sun gear ZS_1 of the first planetary gear mechanism P_1, the first sun gear ZS_1 being the input member of the reduction gear 49.

$$(nr_1/ns_1) \times (nr_2/ns_2) \times (nc_3/ns_3) = nc_3/ns_1 \qquad (9)$$

From Equation (6) to Equation (8), the reduction ratio nc_3/ns_1 of the reduction gear 49 is given by

$$nc_3/ns_1 = (-zs_1/zr_1) \times (-zs_2/zr_2) \times \{zs_3/(zs_3 + zr_3)\} \qquad (10)$$

and in the embodiment, since the number of teeth of each gear is set as follows:

$zs_1 = 18$ $zp_1 = 27$ $zr_1 = 72$

$zs_2 = 96$ $zp_2 = 24$ $zr_2 = 144$

$zs_3 = 168$ $zp_3 = 24$ $zr_3 = 216$,

the reduction ratio nc_3/ns_1 of the reduction gear 49 obtained by substituting these numbers of teeth in Equation (10) is 1/13.7. That is, when the input shaft Si of the reduction gear 49 rotates 13.7 times, the output shaft So rotates once in the same direction.

As hereinbefore described, since the reduction gear 49 is formed by connecting the first to the third planetary gear mechanisms P_1 to P_3, it is possible to increase the torque of the motor 48 while ensuring that there is a sufficient reduction ratio. Furthermore, since the second planetary gear mechanism P_2 is disposed so as to overlap the radially outer side of the first planetary gear mechanism P_1, and the third planetary gear mechanism P_3 is disposed so as to overlap the radially outer side of the second planetary gear mechanism P_2, it is possible to reduce the thickness in the axis L direction of the reduction gear 49 compared with a case in which the first to the third planetary gear mechanisms P_1 to P_3 are all disposed so as to be stacked in the axis L direction. That is, the first electric actuators 12 and the second electric actuators 13 can be made compact by suppressing the thickness of the reduction gear 49 to a thickness corresponding to one planetary gear mechanism while ensuring that there is a reduction ratio corresponding to three planetary gear mechanisms, thereby enabling fitting under a user's clothing with a good appearance.

The structure of a first electric actuator 12 related to a third embodiment of the present invention is now explained with reference to FIG. 11 to FIG. 13.

The structure of a second electric actuator 13 is the same as that of the first electric actuator 12.

A casing 41 of the first electric actuator 12 is formed in a bottomed cylindrical shape having an axis L as the center. The casing 41 is formed by layering a support ring 42, a support plate 44, a motor housing 45, and a motor cover 46 and integrally securing them with a plurality of bolts 47. A motor 48 is housed within the motor housing 45 and the motor cover 46, and a reduction gear 49 is housed within the support ring 42 and the support plate 44. An input shaft Si of the reduction gear 49 is supported on the support plate 44 and the motor cover 46 via ball bearings 50 and 51, a rotor 52 of the motor 48 is fixed to the input shaft Si, and a stator 53 surrounding the outer periphery of the rotor 52 is fixed to the motor housing 45. A permanent magnet 52a and a coil 53a are provided on the rotor 52 and the stator 53 respectively, and when the coil 53a is energized, the input shaft Si rotates together with the rotor 52.

The reduction gear 49, which is housed within the support ring 42, includes a first planetary gear mechanism P_1, a second planetary gear mechanism P_2, and a third planetary gear mechanism P_3; the second planetary gear mechanism P_2 is disposed radially outside the first planetary gear mechanism P_1, and the third planetary gear mechanism P_3 is disposed radially outside the second planetary gear mechanism P_2.

The first planetary gear mechanism P_1 includes a first sun gear ZS_1, a first ring gear ZR_1, a plurality of first planetary gears ZP_1, and a first carrier C_1. The first sun gear ZS_1 is connected to a shaft end of the input shaft Si via an electromagnetic clutch 54. The first ring gear ZR_1 is formed integrally at a position close to the center of the support plate 44 so as to surround the axis L. The first carrier C_1, which rotatably supports the first planetary gears ZP_1 meshing simultaneously with the first sun gear ZS_1 and the first ring gear ZR_1,

is disposed rotatably around the axis L. The first planetary gear mechanism P_1 is therefore of a planetary type in which the first ring gear ZR_1 is fixed and the first carrier C_1 is rotatable, and when the first sun gear ZS_1, which is connected to the input shaft Si via the electromagnetic clutch 54, rotates, the rotation is reduced in speed in the same direction, and output to the first carrier C_1.

The reduction ratio of the planetary type first planetary gear mechanism P_1 is defined as nc_1/ns_1, where ns_1 is an input rotational speed of the first sun gear ZS_1 and nc_1 is an output rotational speed of the first carrier C_1. If zs_1, zr_1, and zp_1 denote the number of teeth of the first sun gear ZS_1, the first ring gear ZR_1, and the first planetary gear ZP_1 respectively, the reduction ratio nc_1/ns_1 is given by

$$nc_1/ns_1 = zs_1/(zs_1 + zr_1). \qquad (11)$$

The second planetary gear mechanism P_2 includes a second sun gear ZS_2, a second ring gear ZR_2, a plurality of second planetary gears ZP_2, and a second carrier C_2. The second sun gear ZS_2 is formed on the outer periphery of the first carrier C_1 of the first planetary gear mechanism P_1. The second ring gear ZR_2 is formed at a position close to the outer periphery of the support plate 44 so as to surround the axis L. The second carrier C_2, which rotatably supports the second planetary gears ZP_2 meshing simultaneously with the second sun gear ZS_2 and the second ring gear ZR_2, is disposed rotatably around the axis L. The second planetary gear mechanism P_2 is therefore of a planetary type in which the second ring gear ZR_2 is fixed and the second carrier C_2 is rotatable, and when the second sun gear ZS_2 rotates, the rotation is reduced in speed in the same direction, and output to the second carrier C_2.

The reduction ratio of the planetary type second planetary gear mechanism P_2 is defined as nc_2/ns_2, where ns_2 is an input rotational speed of

the second sun gear ZS and nc_2 is an output rotational speed of the second carrier C_2. If zs_2, zr_2, and zp_2 denote the number of teeth of the second sun gear ZS_2, the second ring gear ZR_2, and the second planetary gear ZP_2 respectively, the reduction ratio nc_2/ns_2 is given by

$$nc_2/ns_2 = zs_2/(zs_2 + zr_2). \qquad (12)$$

The third planetary gear mechanism P_3 includes a third sun gear ZS_3, a third ring gear ZR_3, a plurality of third planetary gears ZP_3, and a third carrier C_3. The third sun gear ZS_3 is formed on the outer periphery of the second carrier C_2 of the second planetary gear mechanism P_2. The third ring gear ZR_3 is formed integrally with the inner periphery of the support ring 42. The third carrier C_3, which rotatably supports the third planetary gears ZP_3 meshing simultaneously with the third sun gear ZS_3 and the third ring gear ZR_3, is rotatably supported on the inner periphery of the support ring 42 via a ball bearing 57. The third planetary gear mechanism P_3 is therefore of a planetary type in which the third ring gear ZR_3 is fixed and the third carrier C_3 is rotatable, and when the third sun gear ZS_3 rotates, the rotation is reduced in speed in the same direction and output to the output shaft So, which is integral with the third carrier C_3.

The reduction ratio of the planetary type third planetary gear mechanism P_3 is defined as nc_3/ns_3, where ns_3 denotes an input rotational speed of the third sun gear ZS_3 and nc_3 denotes an output rotational speed of the third carrier C_3. If zs_3, zr_3, and zp_3 denote the number of teeth of the third sun gear ZS_3, the third ring gear ZR_3, and the third planetary gear ZP_3 respectively, the reduction ratio nc_3/ns_3 is given by

$$nc_3/ns_3 = zs_3/(zs_3 + zr_3). \qquad (13)$$

Since the output rotational speed nc_1 of the first carrier C_1, which is the output member of the first planetary gear mechanism P_1, is equal to the input

rotational speed ns_2 of the second sun gear ZS_2, which is the input member of the second planetary gear mechanism P_2, and the output rotational speed nc_2 of the second carrier C_2, which is the output member of the second planetary gear mechanism P_2, is equal to the input rotational speed ns_3 of the third sun gear ZS_3, which is the input member of the third planetary gear mechanism P_3, the product of the reduction ratio nc_1/ns_1 of the first planetary gear mechanism P_1 shown in Equation (11), the reduction ratio nc_2/ns_2 of the second planetary gear mechanism P_2 shown in Equation (12), and the reduction ratio nc_3/ns_3 of the third planetary gear mechanism P_3 shown in Equation (13) is given by the ratio nc_3/ ns_1 of the rotational speed nc_3 of the third carrier C_3 of the third planetary gear mechanism P_3, the third carrier C_3 being the output member of the reduction gear 49, relative to the rotational speed ns_1 of the first sun gear ZS_1 of the first planetary gear mechanism P_1, the first sun gear ZS_1 being the input member of the reduction gear 49.

$$(nc_1/ns_1) \times (nc_2/ns_2) \times (nc_3/ns_3) = nc_3/ns_1 \qquad (14)$$

From Equation (11) to Equation (13), the reduction ratio nc_3/ns_1 of the reduction gear 49 is given by

$$nc_3/ns_1 = \{zs_1/(zs_1 + zr_1)\} \times \{zs_2/(zs_2 + zr_2)\} \times \{zs_3/(zs_3 + zr_3)\} \quad (15)$$

and in the embodiment, since the number of teeth of each gear is set as follows:

$zs_1 = 18$ $zp_1 = 27$ $zr_1 = 72$

$zs_2 = 96$ $zp_2 = 24$ $zr_2 = 144$

$zs_3 = 168$ $zp_3 = 24$ $zr_3 = 216$,

the reduction ratio nc_3/ns_1 of the reduction gear 49 obtained by substituting these numbers of teeth in Equation (15) is 1/28.5. That is, when the input shaft Si of the reduction gear 49 rotates 28.5 times, the output shaft So rotates once in the same direction.

As hereinbefore described, since the reduction gear 49 is formed by connecting the first to the third planetary gear mechanisms P_1 to P_3, it is possible to increase the torque of the motor 48 while ensuring that there is a sufficient reduction ratio. Furthermore, since the second planetary gear mechanism P_2 is disposed so as to overlap the radially outer side of the first planetary gear mechanism P_1, and the third planetary gear mechanism P_3 is disposed so as to overlap the radially outer side of the second planetary gear mechanism P_2, it is possible to reduce the thickness in the axis L direction of the reduction gear 49 compared with a case in which the first to the third planetary gear mechanisms P_1 to P_3 are all disposed so as to be stacked in the axis L direction. That is, the first electric actuators 12 and the second electric actuators 13 can be made compact by suppressing the thickness of the reduction gear 49 to a thickness corresponding to one planetary gear mechanism while ensuring that there is a reduction ratio corresponding to three planetary gear mechanisms, thereby enabling fitting under a user's clothing with a good appearance.

The structure of a first electric actuator 12 related to a fourth embodiment of the present invention is now explained with reference to FIG. 14 to FIG. 17. The structure of a second electric actuator 13 is the same as that of the first electric actuator 12.

A casing 41 of the first electric actuator 12 is formed in a bottomed cylindrical shape having an axis L as the center. The casing 41 is formed by layering a first support ring 42, a second support ring 43, a support plate 44, a motor housing 45, and a motor cover 46 and integrally securing them with a plurality of bolts 47. A motor 48 is housed within the motor housing 45 and the motor cover 46, and a reduction gear 49 is housed within the first support ring 42 and the second support ring 43. An input shaft Si of the reduction gear 49

is supported on the support plate 44 and the motor housing 45 via ball bearings 50 and 51, a rotor 52 of the motor 48 is fixed to the input shaft Si, and a stator 53 surrounding the outer periphery of the rotor 52 is fixed to the motor housing 45. A permanent magnet 52a and a coil 53a are provided on the rotor 52 and the stator 53 respectively, and when the coil 53a is energized, the input shaft Si rotates together with the rotor 52.

The reduction gear 49 includes a first planetary gear mechanism P_1 and a second planetary gear mechanism P_2 housed inside the second support ring 43, and a third planetary gear mechanism P_3 housed inside the first support ring 42. The first planetary gear mechanism P_1 is disposed radially inside the second planetary gear mechanism P_2, and the third planetary gear mechanism P_3 is disposed outside, in the axis L direction, the first and second planetary gear mechanisms P_1 and P_2.

The first planetary gear mechanism P_1 includes a first sun gear ZS_1, a first ring gear ZR_1, a plurality of first planetary gears ZP_1, and a first carrier C_1. The first sun gear ZS_1 is connected to a shaft end of the input shaft Si via an electromagnetic clutch 54. The first ring gear ZR_1 is formed integrally with the support plate 44 so as to surround the axis L. The first carrier C_1, which rotatably supports the first planetary gears ZP_1 meshing simultaneously with the first sun gear ZS_1 and the first ring gear ZR_1, is disposed rotatably around the axis L. The first planetary gear mechanism P_1 is therefore of a planetary type in which the first ring gear ZR_1 is fixed and the first carrier C_1 is rotatable, and when the first sun gear ZS_1, which is connected to the input shaft Si via the electromagnetic clutch 54, rotates, the rotation is reduced in speed in the same direction, and output to the first carrier C_1.

The reduction ratio of the planetary type first planetary gear mechanism P_1 is defined as nc_1/ns_1, where ns_1 is an input rotational speed of the first sun

gear ZS_1 and nc_1 is an output rotational speed of the first carrier C_1. If zs_1, zr_1, and zp_1 denote the numbers of teeth of the first sun gear ZS_1, the first ring gear ZR_1, and the first planetary gear ZP_1 respectively, the reduction ratio nc_1/ns_1 is given by

$$nc_1/ns_1 = zs_1/(zs_1 + zr_1). \qquad (16)$$

The second planetary gear mechanism P_2 includes a second sun gear ZS_2, a second ring gear ZR_2, a plurality of second planetary gears ZP_2, and a second carrier C_2. The second sun gear ZS_2 is formed on the outer periphery of the first carrier C_1 of the first planetary gear mechanism P_1. The second ring gear ZR_2 is formed integrally with the inner periphery of the second support ring 43, which is fixed to the casing 41. The second carrier C_2, which rotatably supports the second planetary gears ZP_2 meshing simultaneously with the second sun gear ZS_2 and the second ring gear ZR_2, is rotatably supported on the inner periphery of the second support ring 43 via a ball bearing 56. The second planetary gear mechanism P_2 is therefore of a planetary type in which the second ring gear ZR_2 is fixed and the second carrier C_2 is rotatable, and when the second sun gear ZS_2, which is an input member, rotates, the rotation is reduced in speed in the same direction, and output to the second carrier C_2.

The reduction ratio of the planetary type second planetary gear mechanism P_2 is defined as nc_2/ns_2, where ns_2 is an input rotational speed of the second sun gear ZS_2 and nc_2 is an output rotational speed of the second carrier C_2. If zs_2, zr_2, and zp_2 denote the number of teeth of the second sun gear ZS_2, the second ring gear ZR_2, and the second planetary gear ZP_2 respectively, the reduction ratio nc_2/ns_2 is given by

$$nc_2/ns_2 = zs_2/(zs_2 + zr_2). \qquad (17)$$

The third planetary gear mechanism P_3 includes a third sun gear ZS_3, a third ring gear ZR_3, a plurality of third planetary gears ZP_3, and a third carrier C_3. The third sun gear ZS_3 is formed integrally with the outer periphery of a central part of the second carrier C_2 of the second planetary gear mechanism P_2. The third ring gear ZR_3 is formed integrally with the inner periphery of the first support ring 42, which is fixed to the casing 41. The third carrier C_3, which rotatably supports the third planetary gears ZP_3 meshing simultaneously with the third sun gear ZS_3 and the third ring gear ZR_3, is rotatably supported on the inner periphery of the first support ring 42 via a ball bearing 57. The third planetary gear mechanism P_3 is therefore of a planetary type in which the third ring gear ZR_3 is fixed and the third carrier C_3 is rotatable, and when the third sun gear ZS_3, which is an input member, rotates, the rotation is reduced in speed in the same direction and output to the output shaft So, which is integral with the third carrier C_3.

The reduction ratio of the planetary type third planetary gear mechanism P_3 is defined as nc_3/ns_3, where ns_3 denotes an input rotational speed of the third sun gear ZS_3 and nc_3 denotes an output rotational speed of the third carrier C_3. If zs_3, zr_3, and zp_3 denote the number of teeth of the third sun gear ZS_3, the third ring gear ZR_3, and the third planetary gear ZP_3 respectively, the reduction ratio nc_3/ns_3 is given by

$$nc_3/ns_3 = zs_3/(zs_3 + zr_3). \qquad (18)$$

Since the output rotational speed nc_1 of the first carrier C_1, which is the output member of the first planetary gear mechanism P_1, is equal to the input rotational speed ns_2 of the second sun gear ZS_2, which is the input member of the second planetary gear mechanism P_2, and the output rotational speed nc_2 of the second carrier C_2, which is the output member of the second planetary gear mechanism P_2, is equal to the input rotational speed ns_3 of the third sun

gear ZS_3, which is the input member of the third planetary gear mechanism P_3, the product of the reduction ratio nc_1/ns_1 of the first planetary gear mechanism P_1 shown in Equation (16), the reduction ratio nc_2/ns_2 of the second planetary gear mechanism P_2 shown in Equation (17), and the reduction ratio nc_3/ns_3 of the third planetary gear mechanism P_3 shown in Equation (18) is given by the ratio nc_3/ ns_1 of the rotational speed nc_3 of the third carrier C_3 of the third planetary gear mechanism P_3, the third carrier C_3 being the output member of the reduction gear 49, relative to the rotational speed ns_1 of the first sun gear ZS_1 of the first planetary gear mechanism P_1, the first sun gear ZS_1 being the input member of the reduction gear 49.

$$(nc_1/ns_1) \times (nc_2/ns_2) \times (nc_3/ns_3) = nc_3/ns_1 \qquad (19)$$

From Equation (16) to Equation (18), the reduction ratio nc_3/ns_1 of the reduction gear 49 is given by

$$nc_3/ns_1 = \{zs_1/(zs_1 + zr_1)\} \times \{zs_2/(zs_2 + zr_2)\} \times \{zs_3/(zs_3 + zr_3)\} \quad (20)$$

and in the embodiment, since the number of teeth of each gear is set as follows:

$zs_1 = 18$ $\quad zp_1 = 27$ $\quad zr_1 = 72$

$zs_2 = 96$ $\quad zp_2 = 24$ $\quad zr_2 = 144$

$zs_3 = 36$ $\quad zp_3 = 54$ $\quad zr_3 = 144$,

the reduction ratio nc_3/ns_1 of the reduction gear 49 obtained by substituting these numbers of teeth in Equation (20) is 1/62.5. That is, when the input shaft Si of the reduction gear 49 rotates 62.5 times, the output shaft So rotates once in the same direction.

As hereinbefore described, since the reduction gear 49 is formed by connecting the first to the third planetary gear mechanisms P_1 to P_3, it is possible to increase the torque of the motor 48 while ensuring that there is a sufficient reduction ratio. Furthermore, since the second planetary gear

mechanism P_2 is disposed so as to overlap the radially outer side of the first planetary gear mechanism P_1, it is possible to reduce the thickness in the axis L direction of the reduction gear 49 compared with a case in which the first to the third planetary gear mechanisms P_1 to P_3 are all disposed so as to be stacked in the axis L direction. That is, the first electric actuators 12 and the second electric actuators 13 can be made compact by suppressing the thickness of the reduction gear 49 to a thickness corresponding to two planetary gear mechanisms while ensuring that there is a reduction ratio corresponding to three planetary gear mechanisms, thereby enabling fitting under a user's clothing with a good appearance.

Although embodiments of the present invention are explained in detail above, the present invention can be modified in a variety of ways without departing from the spirit and scope thereof.

For example, the reduction gear 49 of the first embodiment includes the first to the third planetary gear mechanisms P_1 to P_3, but the third planetary gear mechanism P_3 may be omitted and only the first and second planetary gear mechanisms P_1 and P_2 may be employed.

Furthermore, in the first to the fourth embodiments, the electromagnetic clutch 54 is disposed between the input shaft Si and the first sun gear ZS_1, but the electromagnetic clutch 54 may be provided at any position between the input shaft Si and the output shaft So.

INDUSTRIAL APPLICABILITY

As hereinbefore described, the present invention can be suitably applied to a reduction gear for a walking assistance system assisting an injured person or an elderly person with weakened leg force to move.